

SHAPING TOOL WITH STRUCTURED SURFACE FOR CREATING  
STRUCTURES

5 ON GLASS, AND ITS USE IN STRUCTURING CHANNEL PLATES

Specification:

10 The invention relates to a shaping tool with a  
structured surface for creating structures on glass in  
the context of a hot-shaping method, which is employed  
in particular for making precision structures in a  
channel plate of flat screens.

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Plate glass provided with precision structures is  
needed for precision applications, in particular in the  
field of glasses (that is, kinds of glass) that have  
optical functions. Such glasses are for instance  
display screens of new flat screen generations (PDPs or  
plasma display panels, and PALCs or plasma addressed  
liquid crystals). In the so- called channel plate of  
these flat screen glasses, microscopic channel  
structures for triggering individual rows or columns  
are made, which extend over the entire active width or  
height of the screen and in which plasma is ignited via  
an electrical discharge. The boundary on both sides of  
an individual channel is accomplished via rectangular  
ribs, whose width is as slight as possible. To achieve  
an adequate discharge volume, the height of the ribs is  
substantially greater than their width. The spacing of  
the ribs should be as slight as possible.

35 The channel plate thus represents the  
microstructured glass backpanel of a PALC or PDP  
display. It is shown in basic form and in detail on a

greatly enlarged scale in Fig. 7.

5 The channel-like microstructuring shown in this  
drawing figure must be accomplished cost-effectively  
and in large numbers for different display sizes  
(diagonal screen sizes up to 55 inches). For a 42-inch  
HiVision PDP display, for instance, approximately 5760  
channels with a pitch "X" of approximately 161  $m\mu$  and a  
10 rib height Y of 150  $m\mu$  and a rib width "Z" of 30 to 50  
 $m\mu$ , with tolerances of only a few micrometers over a  
length of about 520 mm must be made. These enormously  
stringent specifications dictate a high- precision  
method and a corresponding apparatus.

5 It is known to create structures on glass on the  
basis of a shaping tool with a structured surface,  
using hot- shaping techniques.

20 Conventional hot-shaping methods, so-called  
creative forming methods, are conceived such that hot  
(molten) glass is given its desired form out of the  
melt by means of a cooled shaping tool that is pressed  
into the molten glass. The shaping tool takes on the  
function of "solidification shaping"; that is, before  
25 contact with the tool, the glass has a temperature  
above the glass transition range ( $T_g$ ) and is cooled by  
the contact with the shaping tool in such a way that  
the negative of the structured surface of the shaping  
tool is copied dimensionally stably in the glass.

30 The invention takes as point of departure another  
hot- shaping method, which can be characterized as a  
reshaping warm-shaping process. In this reshaping  
shaping process, the temperature of the glass before it  
35 contacts the shaping tool having the structured surface

is optionally below the glass transition range, and is raised to the requisite temperature range for shaping ( $T > T_g$ ) only by contact with the shaping tool. It is decisive here that only local heating of whatever region is to be structured occurs. In this reshaping process as well, the glass when it leaves the shaping tool is in its structured form and in a dimensionally stable state.

Physical variables, which pertain to both the conventional hot-shaping method and the reshaping warm-shaping method in terms of the process sequence are:

- the temperature of the glass and of the shaping tool;
- the pressure load on the glass and the shaping tool;
- the time of contact of the glass and shaping tool (dwell time).

The following description of the dwell time may make this clearer:

If the glass comes into contact with the shaping tool only briefly, or in other words if the shaping tool is removed from the glass before the solidification occurs, then because of the flowing of the glass structure, major rounding occurs in the structure after contact.

If contact is long-lasting, then major temperature differences and different thermal expansions of the shaping tool and glass result in intolerable lateral strains, which adversely affect the precision of the structures, or in other words the

precision with which the channels in channel plates can be positioned and reproduced.

5 A shaping tool which is intended to be  
appropriate for precise process control must assure an  
independent setting/regulation of the above-described  
variables. The known hot-shaping tools do not meet  
these requirements. Because of their conventional  
10 solid structure with chromium nickel steels, which  
necessitates heating the entire shaping tool  
completely, they furthermore have inadequate thermal  
dimensional stability, because at even relatively  
slight temperature fluctuations in the shaping tool,  
relatively major changes in length of the shaping  
structures occurs, changes that exceed the allowable  
tolerances for forming the channels or ribs.

5  
20 The same applies to the shaping tool, disclosed  
by German Patent DE 197 13 309 C1 and German Patent  
Application DE 197 13 312 A1, with a structured surface  
for creating structures on glass on the principle of  
reshaping warm- shaping, which in the exemplary  
embodiment has a rolling cylinder, comprising a solid  
cylinder of preferably nonmetal material, to which a  
25 molding tool with the structure-imparting surface is  
clamped, resting relatively loosely. On each of the  
two face ends of the solid cylinder, a respective  
bearing journal for the rotational mounting of the  
rolling cylinder is provided. An external heating  
30 source is provided for the requisite local heating of  
the shaping tool.

35 Such an embodiment of the shaping tool does not  
make it possible in practice to create precision  
structures with the desired replicable precision, since

5 the necessary thermal dimensional stability has not  
been adequately taken into account in the design of the  
individual components and in the bearing of the rolling  
cylinder. The enormously stringent specifications  
described at the outset can accordingly not be met.

10 With the shaping tool disclosed by European  
Patent Disclosure EP 0 866 487 A1 as well, the  
enormously stringent specifications discussed at the  
outset cannot be met.

5 This known shaping tool has a solid rolling  
cylinder comprising a metal alloy, and the shaping  
structures are formed directly on its circumferential  
surface. Nothing is said in the European Patent  
reference about the rotational support of the rolling  
cylinder. The glass substrate is plasticized by means  
of an external heat source before the rolling cylinder,  
which is not itself heated directly, in conjunction  
20 with a counterpart roller impresses the desired  
structure into the glass substrate.

25 This European reference again makes no statement  
as to the requirement for fine-tuning of the  
coefficients of thermal expansion and the bearing of  
the rolling cylinder in order to achieve the requisite  
thermal dimensional stability. In particular because  
of the solid rolling cylinder, even at slight  
30 temperature fluctuations, relatively major changes in  
length in the shaping structures occur, which exceed  
the allowable tolerances for forming the channels or  
ribs.

35 Producing channel plates by means of shaping  
tools with structured surfaces has therefore not gained

a foothold in the industry.

5 The production of channel plates is therefore currently done in general by screen printing, in which between 10 and 20 layers of glass solder are deposited, one layer at a time, onto the glass substrate.

This method has the following disadvantages:

- 10
- long process times
  - high solder costs
  - uneven sintering of the channel plates
  - environmental pollution (lead in the solder, etching solutions)
- 5

and therefore from a commercial standpoint allows the production only of prototypes; that is, it is not suited to commercial mass production.

20 It is the object of the invention to create a shaping tool with a structured surface for creating structures on glass that economically makes it possible to form high-precision microstructures in the glass by local heating of the region of glass to be structured, on the principle of reshaping warm-shaping.

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This object is successfully attained by the invention by means of a shaping tool of this kind, having:

- 30
- a rolling cylinder, comprising a metal hollow cylinder, on whose outer jacket a metal shaping sheet, which is provided with recesses corresponding to the negative of the glass structures to be made, is put into intimate large-area contact;
- 35

- a shaft, for continuously driving the rolling cylinder, that extends through the metal hollow cylinder;

5 - two drivers, which are fixedly mounted on the shaft at the level of the face ends of the metal hollow cylinder and are in positive operative engagement with the hollow cylinder; and

10 - an electric heater, which is disposed in electrically insulated fashion between the shaft and the metal hollow cylinder, with an additional thermal insulation from the shaft.

5 Because of the how the hot-shaping tool of the invention is constructed, it is economically possible, by simply rolling along the glass substrate, to form high- precision microstructures on the glass upon contact with the glass, by means of targeted local heating of the glass to be structured.

20 For attaining a constant reshaping temperature, the metal hollow cylinder plays a decisive role; by its thermal capacity, it prevents overly fast cooling upon contact with the glass. This effect is reinforced, in accordance with a feature of the invention, if the material comprising the metal hollow cylinder is a nickel wrought alloy.

25 30 In a further feature of the invention, the transmission of torque between the shaft and the rolling cylinder is established by providing that the drivers have at least three symmetrically distributed trapezoidal claws, and complementary trapezoidal  
35 recesses, which are in mutual operative engagement with

the claws by small contact faces, are embodied on the face end of the metal hollow cylinder. This embodiment prevents an excessive outflow of heat from the rolling cylinder into the shaft. The construction is then free of play at temperature fluctuations within the component and at temperature differences from the rolling cylinder to the driver. As a result, the accuracy of concentricity is assured, or is always the same.

For production engineering reasons, expediently four claws offset by  $90^\circ$  are provided, but in principle any arbitrary number of claws greater than three is possible. The more claws there are, the more the connection corresponds to toothed gearing.

For the features of the invention, and in particular the disposition of the heater, are defined by the dependent claims.

Further characteristics and advantages of the invention will also become apparent from the description of exemplary embodiments of the invention shown in the drawings.

Shown are:

Fig. 1, in a longitudinal section, the construction of the hot-shaping roller according to the invention with a structure-bound rolling cylinder, driver, shaft and heater;

Fig. 1A, a sectional view through the roller of Fig. 1 taken along the line A-A;



Fig. 2, an enlarged detail of the roller of Fig. 1, in a plan view of the coupling of the shaft to the rolling cylinder via the drivers;

Fig. 3, a view of the heater, which is disposed between the shaft and the rolling cylinder of the shaping tool of Fig. 1 and serves to heat the rolling cylinder;

Fig. 4, an end-on front plan view on the shaping tool of Fig. 1, showing the slip ring contacts for supplying energy to the heater of Fig. 3;

Fig. 5, a greatly enlarged detail of the structure- imparting PtAu5 plate which surrounds the roller, for a PDP structure;

Fig. 6, a view corresponding to Fig. 5, but for a PALC structure instead;

Fig. 7, a detail showing a structured channel plate of known channel structure.

In Fig. 1, in a longitudinal section, the basic construction of a preferred embodiment of the hot-shaping tool of the invention is shown. The shaping tool has the shape of a roller generally identified by reference numeral 1, which is rolled continuously at a high contact pressure over a glass substrate 2 (Fig. 1A) to be structured, in that the glass substrate 2 is pulled through in the direction of the arrow under the shaping roller 1.

Special demands must be made of the glass substrate.

5 The production of channel plates for display  
systems, to which the invention preferably pertains,  
generally requires high-quality, specially-developed  
glass substrates 2, which are distinguished by robust  
process performance in all the production steps  
involved. Along with the extreme smoothness of the  
glass substrates, which is responsible in the final  
analysis for contrast sharpness and image resolution  
quality, temperature resistance, chemical resistance,  
10 low weight, and an adapted thermal expansion behavior  
are required.

5 The demands made of the ideal glass substrate for  
modern display technologies can be expressed in general  
and in terms of trends as being flatter, thinner and  
smoother, and at the same time having the most inert  
possible and sturdiest possible behavior in the  
complicated method steps, which are of quite different  
types depending on the type of display, and also being  
20 available at a favorable price (in large dimensions).

5 Boron silicate glasses play an outstanding role  
in many technically oriented glass applications.  
Because there is an inexhaustible number of possible  
chemical composition variations, extraordinary  
25 properties are attainable for this glass family. These  
glasses are especially distinguished by high  
temperature resistance, low thermal expansion, and good  
chemical resistance to aggressive media. Furthermore,  
30 such glasses can be produced even without adding  
alkaline components. These special properties afford  
access to new and technologically quite promising  
modern plate-glass applications.

35 From the above-described operative principle of

flat screens, the following guideline demands of a glass substrate for a channel plate can be derived:

- high temperature resistance ( $T_g \geq 600^\circ\text{C}$ )
- low density ( $< 2.8 \text{ g/cm}^3$ )
- excellent surface quality (planarity, warp, waviness, etc.)
- low shrinkage ( $\leq 20 \text{ ppm}$ )
- no "thermal sag"
- optimal adaptation of the thermal expansion
- high electrical resistance
- low gas permeability
- high transmission
- adequate mechanical strength
- large dimensions
- cost-effective

Along with the Corning overflow fusion method and the down-draw technology, float technology above all allows the cost-effective manufacture of large-size glass substrates with excellent surface qualities and with properties adapted to the production process for the display in question.

The embodiment of the shaping tool 1 is determined by the specific demands listed at the outset.

These involve essentially furnishing the following:

- a structured shaping tool for creating the glass structure;
- a shaping tool resistant to bending, for absorbing the rolling forces;

- a shaping tool for continuous production (which is attained by means of the roller structure); and
- a regulatable hot tool.

These conditions are met by the shaping roller 1 shown, which is constructed of four central components. These four central components are: a rolling cylinder 2, two drivers 4, a shaft 5, and a heater 6, which for the sake of clarity is shown separately in Fig. 3.

The rolling cylinder 3 forms the shaping part of the tool, because it carries on it the negative of the structure to be created. The rolling cylinder first comprises a load-bearing metal hollow cylinder 7, for instance with a length of 300 mm, an outer diameter of 120 mm, and a wall thickness of 12 mm.

The material comprising the rolling cylinder is preferably a nickel wrought alloy with the material No. 2.4816. The advantage of a metal alloy over a ceramic material is the high coefficient of thermal expansion of metals, which compared with ceramics is only slightly different from glass coefficients. The following table shows examples of differential expansion coefficients of various materials that can be used:

Material Category	Material	Differential Coefficient of Expansion at 800°C	Difference in Differential Coefficient of Expansion from the Glass Coefficient
5	Glass	AF45	$\alpha_{800^{\circ}\text{C}} \approx 37 \cdot 10^{-6}/\text{K}$
10	Ceramic	Quarzal	$\alpha_{800^{\circ}\text{C}} \approx 0.5 \cdot 10^{-6}/\text{K}$ $\Delta\alpha_{800^{\circ}\text{C}} \approx 36.5 \cdot 10^{-6}/\text{K}$
	Metal	Inconel	$\alpha_{800^{\circ}\text{C}} \approx 20 \cdot 10^{-6}/\text{K}$ $\Delta\alpha_{800^{\circ}\text{C}} \approx 17 \cdot 10^{-6}/\text{K}$

5 If temperature fluctuations occur during the rolling, the dimensional deviation of the product is less, because of the small difference in the coefficients of expansion of the metal roller and glass, than if a ceramic roller is used.

20 The calculation below is intended to illustrate the subject matter more clearly.

25 The tolerance in a structure in the glass, over a substrate length of 100 mm, should amount for instance to no more than  $\pm 10 \mu\text{m}$ . Within the allowable amount of temperature fluctuations, the advantage of a metal roller over a ceramic roller is quite apparent. For the metal tool, a temperature difference of  $\pm 4.8$  kelvins (K) is still possible, while a ceramic tool allows a temperature fluctuation of only  $\pm 2.8\text{K}$ . Dimensional deviations resulting from an uneven temperature distribution in the tool can be eliminated by means of a corrective tool contour design (such as a convex or concave form of the jacket face).

35 A metal sheet 8 with a thickness of 1 mm, for example, into which the negative of the glass structure required has

been machine, is applied over the entire circumference to the outer surface of the metal hollow cylinder 7. For reasons of scale, these negative contours cannot be shown in Fig. 1.

They can be inferred from the greatly enlarged detail views in Figs. 5 and 6, specifically for a PDP channel structure in Fig. 5 and for a PALC structure in Fig. 6. The recesses in the sheet 8 are therefore complementary to the ribs in the channel plate of Fig. 7.

One important aspect in terms of process suitability and economy is the material used for the sheet 8.

Tools that are used in the field of hot shaping of glass in fact make extremely stringent demands of the tool material to be employed. In selecting the material, the following criteria must therefore be taken into account:

- no tendency to adhere to the glass
- no corrosion or oxidization
- high thermal strength (durability)
- low wear
- cost-effectiveness.

For the rolling tool of Fig. 1, which is intended to use in microstructuring glass, the following additional demands must be met:

- microstructurability
- heatability (good thermal conduction)

Scientific material testing and long years of experience in the manufacture of shaping tools for hollow glass shaping have shown that platinum or platinum alloys, such as PtAu5 alloys, with a pure PtAu5 material or alternatively with an oxide-dispersed PtAu5 material (ODS),

best meet the demands made in terms of little tendency to adhere to glass and little corrosion or oxidization.

However, these materials have low thermal resistance, are not optimally wear-resistant, and are moreover very expensive. The low thermal resistance, which causes a loss of structure accuracy in the rolling tool, is disadvantageously expressed accordingly in the glass structure as well.

The material wear resulting from the low hardness of the PtAu5 material does on the other hand offer the important advantage of allowing mechanical, metal-cutting machining of the structuring. The requirement for high abrasion resistance makes for corresponding difficulties in microstructuring, yet is the essential prerequisite to the use of the roller. It is up to one skilled in the art to find the optimal compromise for a specific application.

Instead of the PtAu5 alloy, it is also conceivable to use materials employed in the glass industry that are coated, in order to reduce their tendency to adhere or to increase their wear resistance, as the tool material.

The following material combinations are conceivable:

Bulk Materials:	Inconel	Coating materials:	SiC
	Nicrofer		BC/N
	Nimonic		TiC/N
	Udimet		TiAlN
	Incoloy		MoS <sub>2</sub>
	PM 2000		Pt, Au alloys
			Ni-P
			Hard gold

The goal in each case is a combination of materials that leads to a wear-resistant, microstructurable, heat-conducting material with an only slight (or no) tendency to adhere to the glass.

5

To improve the compatibility of the tool and glass and to improve the wear resistance of the surface, the metal sheet must be bonded very intimately with the fundamental metal hollow cylinder 7.

10

In a particular embodiment, the sheet 8 is hot-isostatically pressed on (hipped). This is a large-area diffusion welding process that involves a complete fusion of material.

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Instead of the hot-isostatic pressing, in principle any method for surface refinement can be employed, and the corresponding metal, ceramic or refined coatings can be applied either before the structuring using the negative structure, or after.

20

The embodiment of the structures in the sheet 8 has a definitive influence on the quality of the glass structures to be made, because to make the microstructures in the glass, the glass must be made to flow into the rolling grooves 8a (Figs. 5 and 6). The nature of the microstructure (grooves extending all the way around the tool) has a major influence on the possibilities for mechanically anchoring the glass composition during the shaping. For this reason, extremely smooth channel flanks without undercuts are of enormous importance, if the hot-shaping process is to be successful. Another requirement is minimal roughness of the tool surface, since in the rolling operation the tool structure and any peaks and valleys or defects in it will be copied exactly in the deformed glass.

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In summary, the following demands are made of the structured rolling tool:

- 5       · exact geometric copying of the negative of the glass structure required
- high smoothness and low roughness of the channel flanks and of the surface
- adherence to a requisite unmolding angle.

10       The microstructuring of the roller body 1 is dependent essentially on the machinability of the material comprising the metal sheet 8. In general, the following methods are conceivable:

- 5       · laser machining
- wire erosion
- grinding
- turning on a lathe
- embossing
- 20       · milling
- etching
- hobbing erosion

25       Each method makes different demands of the material to be structured.

In the industry, the following methods are especially worth considering:

- 30       · laser machining
- erosion
- grinding
- precision turning on a lathe;

35       precision turning by means of a monocrystalline natural

diamond is especially important for microstructuring, as tests have shown.

5 For turning the hollow rolling cylinder 3, the  
aforementioned drivers 4, which are fixedly disposed on the  
shaft 5, are provided.

10 The drivers 4 therefore serve to transmit torque  
between the shaft 5 and the rolling cylinder 3. The  
connection of the drivers with the rolling cylinder is formed  
by four trapezoidal claws 4a (Fig. 2) each that are in  
operative engagement, with play, with four trapezoidal  
grooves 3a formed, extending radially, on both ends of the  
rolling cylinder 3. This number is solely an example. There  
5 may also be three, six or eight pairs of claws in symmetrical  
distribution, or any other number greater than three.

20 This claw drive with clearance on the one hand, by its  
geometrical shape, enables axial and radial thermal  
expansions, or in other words different thermal expansions  
between the cylinder and the driver, and on the other,  
because only small surface areas contact another, allows only  
slight heat losses from the rolling cylinder to the drivers.

25 This drive construction makes it possible, to great  
advantage for the accuracy of the microstructures, to achieve  
a defined position of the rolling cylinder despite the  
considerable thermal expansions.

30 To minimize coupling (the input of inductive power)  
with the attendant power loss, the drivers 4 are provided  
with axial slits 4b (Fig. 2) on the side toward the rolling  
cylinder.

35 The metal material used for the drivers 4 is

preferably the same as for the rolling cylinder (material No. 2.4816), which has sufficient strength at the high operating temperatures.

5 The shaft 5 connects a drive mechanism 9, indicated symbolically on the face end, with the drivers 4 and carries both the heater 6 and its hookups 6a, 6b. It is supported in locating-nonlocating bearings 12, 13 with prestressed  
10 precision spindle bearings, which allow freedom of axial and radial play. The torque between the shaft 5 and the drivers 4 is transmitted via a frictional engagement (bracing of the components). To protect against corrosion and wear, an  $\text{Al}_2\text{O}_3$  coating is applied in the contact region of these components.

5 The drivers and the shaft 5 are axially braced against one another by means of shaft nuts 10 and cup springs 11 and therefore, because of their disposition, allow different thermal expansions between the drivers/rolling cylinder and the shaft. The shaft 5 in this arrangement takes on the  
20 function of a tie rod, which leads to increased rigidity of the rolling cylinder 3.

25 To make it possible to dispose the current supply leads - to be described hereinafter - for the heater, the conduits for the air cooling and the hookups for the thermocouple (temperature measurement), the shaft 5 is embodied as a hollow shaft. To keep the power losses in the shaft during electric heating slight, the shaft is made with  
30 six longitudinal slits 5a (Fig. 1A) distributed uniformly over the circumference; this prevents induction current losses from developing in the shaft.

The shaft 5 preferably comprises the highly heat-resistant material No. 2.4879.

The heater 6 is disposed in the region between the rolling cylinder 3 and the shaft 5. Acting as the hot conductor is a PtRh10 strip 6c (20 by 1.5 mm), which is wound in grooves 14a of a ceramic cylinder 14 into a coil as shown in Fig. 3.

This ceramic cylinder 14 insulates the shaft 5 both electrically and thermally from the hot conductor 6c. Quarzal can be used in particular as the material for the ceramic cylinder.

The rolling cylinder 3 is electrically insulated from the hot conductor 6c by an approximately 2 mm thick quartz glass tube 15. The slight spacing assures fast, low-loss heat transmission, and the transmission properties of the quartz glass assure a good exchange of radiation.

Because of the aforementioned geometric construction, both indirect heating (resistance heating) and direct heating (inductive heating) of the rolling cylinder are possible. The heat required for the manufacturing process can be varied in a known manner by regulating the voltage potential or the current intensity.

Instead of the hot conductor strip 6c, other geometries may be employed, in particular wire, rod or tube profiles. Still other hot conductor materials, in particular kanthal or nicrothal alloys or noble metal alloys, can also be used as the material, depending on the thermal stress.

The supply of energy to the heater is accomplished by means of a slip ring contact assembly 16 on one shaft end, and rod elements 6a, 6b (Fig. 3) in the (hollow) shaft 5.

Fig. 4 in plan view shows further details of the slip

ring contact assembly 16. It fundamentally comprises four double-leg carbon holders 16a with silver graphite carbon 16b, which each slip in pairs on a respective cylinder portion 16c, to which a respective end of the current lead 6a, 6b (Fig. 3) is extended. Clamps 16d serve to hook up the supply lines.

To prevent overheating of the shaft 5, two ceramic tubes 17 are installed in the interior of the shaft, and by means of these tubes, cool air is blown into the center of the shaft; this air can exit again on both ends. A thermocouple 18 (Fig. 1A) in the middle of the coil, with a terminal 18a (Fig. 1) extended to the outside, makes it possible to monitor the temperature and regulate the heater.

This heater can be operated with air cooling as an ohmic resistance heater (50 Hz). As the type of heating, medium-frequency induction heating is optionally usable, which uses either copper (water-cooled) or noble metal (without cooling) as its electrical conductor.

The heater is an essential component of the shaping roller according to the invention, because the shaping process by reshaping, which is the point of departure for the invention, requires a targeted reheating of the glass substrate. This reheating is effected by purposefully heating the rolling cylinder 3 to a temperature that is higher than  $T_g$ , that is, the glass transition temperature of the glass to be structured. To create fine structures close to the shaping tool on only the surface of the substrate, accurate temperature control is necessary, in which the least toughness of the glass occurs in the boundary layer between the shaping tool and the glass. This requires a higher tool temperature in comparison to the glass temperature of the typically preheated glass substrate.

On the other hand, by means of the hot tool a temperature gradient is built up in the substrate, which leads to thermal stresses. The necessity of minimizing these stresses, in order to avoid breakage, determines the lower limit of the outset temperature of the glass before the shaping. In the depressurization range, it is above the  $T_g$  point (at a toughness of about  $10 \text{ E} + 12 \text{ dPa s}$ ). In order then to influence the fundamental structure of the starting material as little as possible, the outset temperature of the glass should be kept as low as possible.

For the shaping, the temperature of the thin surface layer of the glass that is involved, by material transport, in the reshaping process is crucial. This shaping temperature is equivalent to a mixture of the temperatures of the tool and the glass before contact. Other essential influences are exerted by the properties of the components, such as thermal conductivity and thermal capacity. Since heat is flowing from the hot tool into the colder workpiece during the entire shaping time, a constant supply of heat to the tool at the contact point must be assured, so as to maintain the flow of material into the grooves. In the present case, this is done by means of heating the interior of the roller, which because of the solid metal hollow cylinder 7 has a high thermal capacity. A high tool temperature and hence a high boundary face temperature does speed up the shaping process, but also speeds up the heating throughout the specimen, which is of limited thickness and thereby loses so much stability that it is no longer possible to separate the intimately formed-on tool from the specimen without destroying the specimen. The destabilization if the temperature is raised and/or the shaping time is shortened can be ascribed to the severely bent toughness/temperature curve.

The requisite shaping time for forming a desired structure, particularly ribs whose height is greater than their width, is determined by flow events into a gap. The limiting factors are as follows:

- pressure: linear
- toughness: linear
- height: quadratic
- width: quadratic

Suitable deformation times in the rolling process, for a roller 120 mm in diameter (shaping engagement width approximately 3 mm) are on the order of 1.5 seconds (rolling speed: 2 mm/sec).

The shaping forces are generated by pressing the shaping roller 1 against the softening (viscous) glass. They thus occur in the form of internal pressure in a liquid, and not as stresses, as long as the shaping speeds remain low enough. The pressure that triggers the flowing of the glass into the gaps 8a of the tool is thus determined as force/contact area of the roller on the glass 2. This area is dependent on the roller diameter and on the depth to which the roller is lowered, and thus also on the shaping temperature.

The shaping roller according to the invention, by its construction, enables a suitable kind of process control, which in a way that was previously impossible leads to precise microstructuring by precise adherence to the aforementioned reshaping parameters.